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Rb-Sr Isotopic Data from Three Suites of Igneous Rocks, Cape Breton Island, Nova Scotia

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Rb-Sr isotopic data is presented for three suites of igneous rocks: the Fourchu Group; volcanic rocks from Ingonish Island; and the Gulch Brook pluton. Results from the Late Precambrian metavolcanic rocks of the Fourchu Group show considerable scatter due to varying degrees of resetting of the Rb-Sr system. Seven of the eight samples yield an age of 407 ± 46 Ma which is believed to reflect the effects of the Acadian Orogeny in this area. A two-point whole-rock isochron from the two freshest samples yield a c. 640 Ma age which could approximate the extrusive age. The redistribution of strontium and rubidium isotopes suggests that the initial $^{87}Sr/^{86}Sr$ ratios in the range 0.703-0.705 should be viewed with caution.

A whole-rock Rb-Sr isochron for volcanic rocks from Ingonish Island yield an age of 412 ± 15 Ma, interpreted to closely date the time of extrusion and crystallization. An initial $^{87}Sr/^{86}Sr$ ratio of 0.706 suggests the lower crust as one possible source region.

The 413 ± 10 Ma Rb-Sr whole-rock isochron obtained from samples of the weakly foliated Gulch Brook pluton in northern Cape Breton Island probably represents the age of crystallization. Micas, which define the weak foliation in the pluton, have previously yielded a Rb-Sr mineral isochron of 320 Ma or individually calculated ages of 363 Ma for muscovite and 350 Ma for biotite (Cormier, 1980; written comm. 1984) and are believed to represent resetting by a later thermal event during the Late Devonian-Early Carboniferous. The initial $^{87}Sr/^{86}Sr$ ratio of 0.7045 ± 0.0004 suggests a lower crustal source for the magma, possibly with a mantle component as well. The similarity of the ages and initial $^{87}Sr/^{86}Sr$ ratios of the Ingonish Island volcanic rocks and the Gulch Brook Pluton suggest that they may be volcanic/subvolcanic equivalents of one another.

On présente les signatures isotopiques Rb-Sr de trois séries de roches ignées: le groupe de Fourchu, des volcanites de l'île d'Ingonish et le pluton de Gulch Brook. L'analyse des métavolcanites tardiprécambriennes du groupe de Fourchu montre une très grande dispersion des valeurs imputable au réajustement à divers degrés du système Rb-Sr. Sept des huit échantillons ont donné un âge de 407 ± 46 Ma qui semble traduire les effets de l'orogénie acadienne dans ce secteur. Un isochrone de roche globale à deux points, provenant des deux échantillons les moins altérés, a produit un âge autour de 640 Ma qui pourrait approximer l'âge de l'épanchement. La redistribution des isotopes de strontium et rubidium rend discutables les rapports $^{87}Sr/^{86}Sr$ initiaux aux environs de 0.703-0.705.

Un isochrone Rb-Sr de roche globale pour les volcanites de l'île d'Ingonish a rendu un âge de 412 ± 15 Ma qui correspondrait de très près au temps de l'extrusion et la cristallization. Le rapport $^{87}Sr/^{86}Sr$ initial de 0.706 évoque une genèse crustale profonde.

Des échantillons provenant du pluton très peu folié de Gulch Brook, dans l'île du Cap-Breton septentrionale, ont produit un isochrone Rb-Sr de roche globale de 413 ± 10 Ma qui date probablement l'âge de sa cristallization. Une étude antérieure des micas (qui impriment au pluton sa faible

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foliation) a déjà donné un isochrone Rb-Sr de minéral de 320 Ma ou des âges calculés de façon individuelle de 363 Ma pour la muscovite et 350 Ma pour la biotite (Cormier, 1980; comm. écrite, 1984). On pense y deviner un réajustement lié à un épisode thermique ultérieur tardidévonien ou éocarbonifère. Le rapport $^{87}Sr/^{86}Sr$ initial de 0.7045 ± 0.0004 suggère une participation de la croûte continentale inférieure avec une possible contribution mantellique. La similitude des âges et des rapports $^{87}Sr/^{86}Sr$ initiaux des volcanites de l'île d'Ingonish ainsi que du pluton de Gulch Brook nous invite à considérer leur consanguinité.

INTRODUCTION

Fossiliferous pre-Carboniferous rocks in Cape Breton Island occur in only a few isolated areas in the southern part. Thus, constraints on the ages of rock units and events affecting the rocks are absent in many areas, and isotopic dating provides the only available means for determining these ages. This paper presents Rb-Sr isotopic data from three suites of felsic volcanic rocks: the Fourchu Group from southeastern Cape Breton Island and volcanic rocks from the Ingonish area; and a suite of granitoid rocks from the Gulch Brook microgranitic pluton in the Cape North area (Fig. 1).

TECHNIQUES

Rb-Sr isotopic analyses were carried out at the Scottish Universities Research and Reactor Centre using standard techniques described in detail elsewhere (Halliday *et al.*, 1979, 1983). Sample powders spiked with ^{87}Rb- and ^{84}Sr-enriched isotopic tracers were dissolved using hydrofluoric, nitric and hydrochloric acids and Rb and Sr separated using conventional cation exchange resins. Isotopic analyses were performed on a fully automated V.G. Isomass 54E mass spectrometer. $^{87}Sr/^{86}Sr$ ratios are reported normalized to $^{88}Sr/^{86}Sr$ = 8.37521. The average $^{87}Sr/^{86}Sr$ for NBS987 on this machine was 0.71027±1 2σ mean, N=79) at the time of analysis. Regression followed the method of York (1969). The decay constant for ^{87}Rb used is $1.42 \times 10^{-11} y^{-1}$. The uncertainty in $^{87}Rb/^{86}Sr$ is estimated to be ±1.0% (2σ).

FOURCHU GROUP

The Fourchu Group in southeastern Cape Breton Island consists mainly of pyroclastic rocks with a few flows of calc-alkaline basalt, andesite and rhyolite (Weeks, 1954; Keppie *et al.*, 1979). Several small mafic and felsic intrusive bodies are inferred to be subvolcanic, and some dykes and sills are interpreted to have been feeders to the volcanic pile. The rocks were subsequently deformed and metamorphosed to greenschist facies during the Late Hadrynian-Cadomian Orogeny (Keppie, 1979; 1982), before being eroded and unconformably overlain by the Lower Cambrian Morrison River Formation and other rocks of Cambrian-Ordovician age. Unconformable contacts are not known to be exposed in Cape Breton Island, however clasts of the Fourchu Group were deformed and metamorphosed prior to their incorporation in the Cambrian sediments (Keppie, 1982). The Fourchu Group is cut by the Capelin Cove and Loch Lomond granitoid plutons dated at 545 ± 28 Ma and 548 ± 18 Ma using the whole-rock Rb-Sr isochron method (Keppie and Smith, 1978, recalculated from Cormier, 1972, using 1.42×10^{-11} y^{-1} decay constant for ^{87}Rb). Following the deposition of Cambrian-Ordovician rocks, the area was subjected to gentle folding, of probable Acadian age, before being intruded by granitoid plutons yielding whole-rock Rb-Sr isochron ages of 384 ± 10 Ma (Cormier, 1979), 357 ± 11 Ma (Cormier, 1980), and 368 ± 30 Ma (Barr, *et al.*, 1984).

Fairbairn *et al.* (1966) attempted to date the Fourchu Group and obtained a whole-rock Rb-Sr isochron age of 504 ± 24 Ma (recalculated by Keppie and

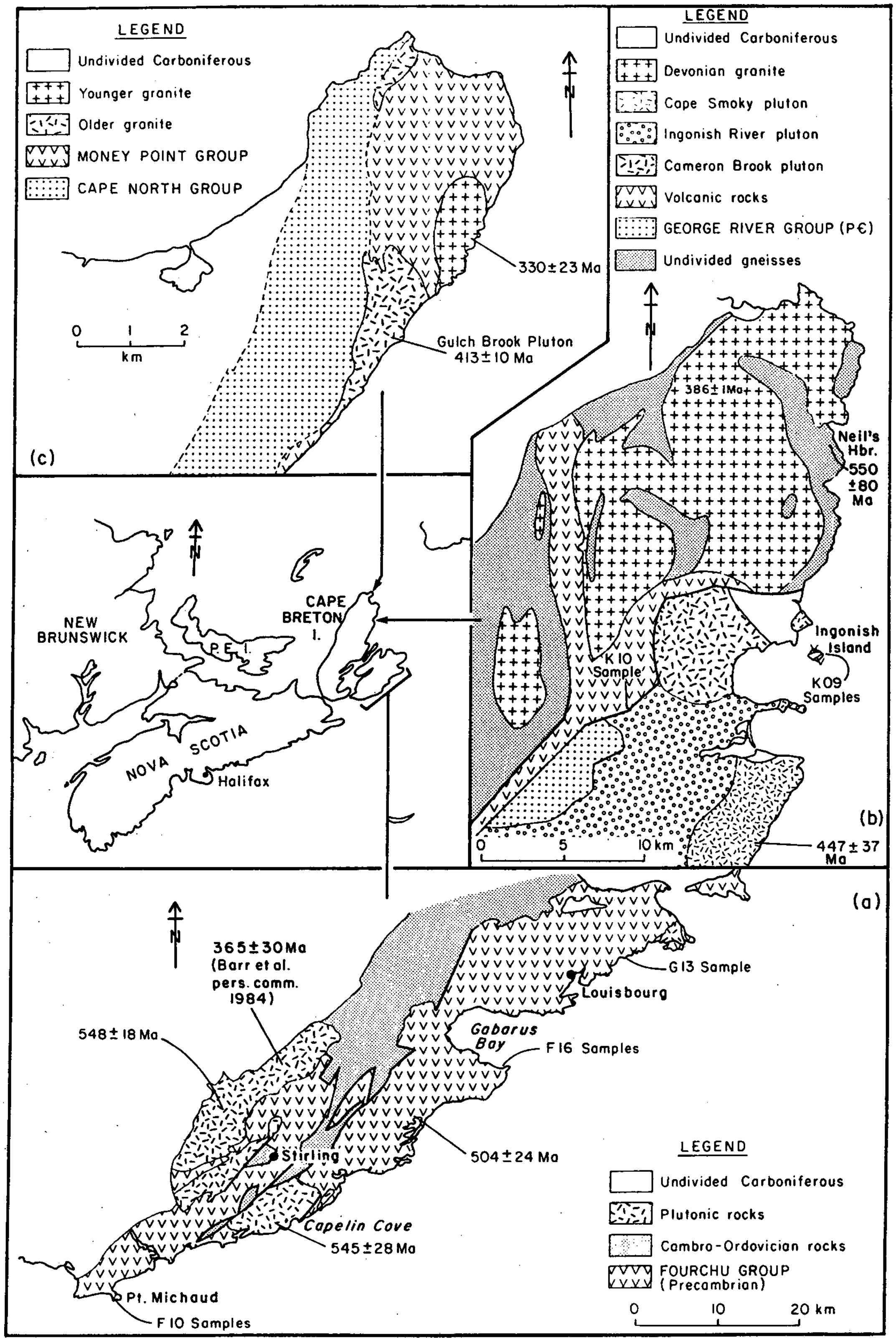

Figure 1. Maps showing sample locations (geology modified from Keppie, 1979).

Smith, 1978) and an initial $^{87}Sr/^{86}Sr$ ratio of 0.705 ± 0.001 for rhyolites from both the type area and the East Bay hills to the northwest. With the base of the Cambrian placed at c. 570 Ma this age is clearly too young, probably due to post-extrusion remobilization of strontium or rubidium. In an attempt to minimize these secondary effects in the present study, samples of a porphyry body were included with the least altered samples of rhyolite. The porphyry is inferred to be subvolcanic because, although it cuts the host volcanic rocks, they were subsequently deformed and metamorphosed together.

The rhyolite samples were collected from an area east of Louisbourg (G13) and from Pt. Michaud (F10) (Fig. 1a). They consist of quartz and albitic plagioclase phenocrysts set in a matrix of quartz, feldspar, sericite, chlorite ± epidote, calcite, apatite and opaque minerals. The quartz-feldspar porphyry samples (F16) were collected from the south side of Gabarus Bay (Fig. 1a) and consist of quartz and oligoclase set in a fine-grained matrix of quartz, feldspar, sericite, chlorite, epidote and opaque minerals. All of the samples possess a weak foliation and have been affected by greenschist facies metamorphism.

Rb-Sr isotopic data for the eight samples of the Fourchu Group are given in Table 1. Repeat analyses of three of the samples are also given and show perfect agreement within analytical uncertainties. On a conventional isochron diagram (Fig. 2) the data display considerable scatter, suggesting subsolidus redistribution of Sr or Rb. The two least altered samples, F16-6995 and F10-6995, can be joined by a line corresponding to an age of 636 ± 10 Ma. Assuming they were derived with the same initial $^{87}Sr/^{86}Sr$ and have subsequently remained undisturbed this represents the time of volcanism. However, the latter assumption is probably not justified. The initial $^{87}Sr/^{86}Sr$ in this case is 0.7031 ± 1 (2σ). Seven of the eight samples (that is, excluding F10-6995) scatter about a best fit line corresponding to an age of 407 ± 46 Ma, with an initial $^{87}Sr/^{86}Sr$ of 0.7048 ± 8 (2σ scatter errors), the mean squared weighted deviate (MSWD) value being high (170).

Evaluation of these data in relation to known geological events suggests that the c. 640 Ma age could represent the extrusive age of the Fourchu Group. However, the low initial $^{87}Sr/^{86}Sr$ ratio of 0.7031 ± 1 (2σ) suggests a mantle origin. This does not agree with the conclusion that the felsic rocks result from anatexis of crustal rocks, based upon the high proportion of felsic rocks in the Fourchu Group and the contents of incompatible elements (Keppie et al., 1979). It is probable that some redistribution of the Rb-Sr has taken place during the resetting event. Using the "subsystem" represented by the 7 samples to construct the 407 Ma "isochron", we can calculate a $^{87}Sr/^{86}Sr$ ratio at 407 Ma weighted by the Sr content of the sample as 0.70480, essentially identical to that derived by regression of the "isochron" data. If we assume that the 7 samples are a valid representation of the variation in the reset system, this system had a $^{87}Sr/^{86}Sr$ ratio of 0.70480 at 407 Ma and its present day bulk $^{87}Rb/^{86}Sr$ can be calculated as 1.424. If this subsystem had undergone only internal redistribution of Sr then its initial $^{87}Sr/^{86}Sr$ at the supposed time of crystallization (636 Ma) was the very (unlikely) low figure of 0.7001. There are three possible explanations: the volcanics are much younger than this; or the Sr in the system has been exchanged with Sr from an external low $^{87}Sr/^{86}Sr$ reservoir; or the Rb/Sr ratios have been increased in the subsolidus significantly later than initial crystallization.

Thus, the 640 Ma age should be viewed with caution. The 407 ± 46 Ma age appears to record the resetting of the Rb-Sr system during the Acadian

Orogeny. This age spans the 400-420 Ma age of the Acadian Orogeny determined elsewhere in the Avalon Zone in the Canadian Appalachians (Keppie et al., 1983).

INGONISH ISLAND VOLCANIC ROCKS

The Ingonish area of northern Cape Breton Island is underlain by three contrasting north-south trending belts of rocks (Raeside et al., 1984). A western belt of high grade ortho- and paragneiss is separated by a mylonite zone from the Ingonish River metasedimentary unit, composed of polydeformed pelitic, semipelitic, psammitic and calcareous metasedimentary rocks, interbedded with metavolcanic rocks, metamorphosed to lower greenschist - upper amphibolite facies and intruded by quartz diorite. The eastern belt consists almost entirely of plutonic rocks in which the

Table 1. Analytical and statistical data for the Fourchu Group

Sample Number	Rb (ppm)	Sr (ppm)	Rb/Sr (Weight)	$^{87}Rb/^{86}Sr$ (atomic)	$^{87}Sr/^{86}Sr \pm 2\sigma_M$ (atomic)
F10-6999	70.32	78.55	0.8952	2.593	0.72088 ± 6
G13-6995	73.17	110.2	0.6640	1.923	0.71563 ± 5
F16-6996	60.14	219.1	0.2745	0.7942	0.70900 ± 2
repeat	60.14	219.3	0.2742	0.7934	0.70898 ± 3
F16-6995	48.53	215.9	0.2248	0.6504	0.70899 ± 3
F16-6994	85.43	128.2	0.6662	1.929	0.71625 ± 2
F16-6998	86.04	121.3	0.7092	2.054	0.71630 ± 3
F16-6996	52.14	94.28	0.5530	1.601	0.71370 ± 3
repeat	52.31	94.15	0.5556	1.608	0.71374 ± 3
F16-6995	69.12	94.94	0.7281	2.109	0.72225 ± 4
repeat	69.15	94.87	0.7289	2.112	0.72225 ± 2

$2\sigma M$ = 2 standard errors of the mean (5th digit after decimal point)

Suite	N	*Age ± 2σ a.p. (s.e.) Ma	*$(^{87}Sr/^{86}Sr)$ initial ± 2σ a.p. (s.e.)	SUMS†	MSWD^x
Fourchu Group	8	486 ± 4 (± 113)	0.70382 ± 7 (± 202)	5072	845
ditto minus F10-6995	7	407 ± 4 (± 46)	0.70481 ± 6 (± 81)	850	170
F16-6996 F10-6996 G13-6995 F10-6998	4	410 ± 6 (± 4)	0.70436 ± 11 (± 8)	1.2	0.59
F10-6995 F16-6995	2	636 (± 10)	0.70309 (± 13)	0	∞

N = number of samples
*± 2σ a.p. (s.e.) = Age ± 2 *a priori* (York's scatter error)
†SUMS = sum of the squares of the residuals (York, 1969)
^{x}MSWD = mean squared weighted deviates (York, 1969)

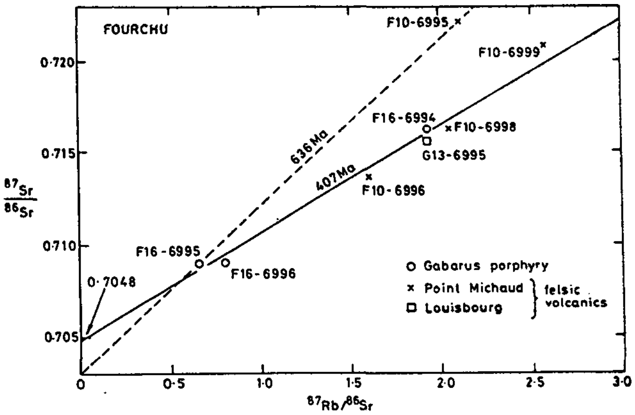

Figure 2. Rb-Sr whole rock isochrons for the Fourchu Group.

inferred sequence is: gneissic tonalite/orthogneiss, dioritic complex ($^{40}Ar/^{39}Ar$ age on hornblende = 560 Ma; Barr _et al._, 1985), Ingonish River Pluton, small intermediate plutons, Cape Smoky Pluton (Rb-Sr whole-rock isochron = 447 ± 37 Ma; Cormier, 1972; 1980), Cameron Brook Pluton (Rb-Sr whole-rock isochron = 445 ± 16 Ma; O'Beirne-Ryan _et al._, 1986) and the Warren Brook, Black Brook and White Point plutons (Rb-Sr whole-rock isochron = 386 ± 1 Ma; Cormier, written communication, 1984). Given this sequence of events, the Ingonish River metasedimentary unit is probably Precambrian. Weibe (1972), Murray (1977) and Keppie (1979) correlated part of this unit with the Precambrian George River Group of southern Cape Breton Island. Raeside _et al._ (1984) and Barr _et al._ (1985) believed such a correlation to be tenuous although they agree that they could be facies equivalents.

The volcanic rocks on Ingonish Island have been correlated with those in the Ingonish River metasedimentary unit (Wiebe, 1972; Murray, 1977; Raeside _et al._, 1984), however they are relatively unmetamorphosed and mildly deformed. The volcanic rocks of Ingonish Island are unconformably overlain by the Lower Carboniferous Windsor Group. Most of the samples for the present study were collected on Ingonish Island with one sample from Clyburn Brook (Fig. 1b). The samples are rhyolites and dacites some of which are porphyritic with plagioclase ± quartz phenocrysts set in a matrix of quartz, feldspar, sericite, ± chorite, ± biotite, ± calcite, ± epidote and opaque minerals. The sample from Clyburn Brook possesses a distinct foliation and was metamorphosed in the greenschist facies.

Isotopic data for all the samples are given in Table 2. Data from the Ingonish Island samples define a best fit line corresponding to an age of 412 ± 15 ma (2σ scatter errors) (Fig. 3). This age is interpreted to closely approximate the time of extrusion and crystallization. This corresponds to a Late Silurian to Early Devonian age using the time scale of Palmer (1983). The initial $^{87}Sr/^{86}Sr$ ratio of 0.7059 ± 0.0005 suggests a lower crustal source for these felsic volcanic rocks. The data from the Clyburn Brook sample is also close to this isochron (Table 2, Fig. 3) and might be taken to confirm Weibe's (1972) correlation. However, the field relations cited earlier, together with the deformed and metamorphosed nature of the volcanic rocks exposed in Clyburn Brook, suggests that this latter suite is older. Clearly more geochronological data are required to resolve this problem.

GULCH BROOK PLUTON

The Cape North area has been mapped most recently by Macdonald and Smith (1980) who showed that the country rocks consist of two conformable groups: medium to high-grade paragneisses of the Cape North Group (possible correlatives of the Precambrian George River Group) and low to medium-grade metavolcanic and metasedimentary rocks of the Money Point Group (Fig. 1c). These rocks were subjected to three main phases of pervasive deformation which were tentatively assigned to the Late Hadrynian - Cadomian Orogeny (D_1 and D_2) and the Acadian Orogeny (D_3). Accompanying, regional, Barrovian-like metamorphism reached its peak during

Table 2. Analytical and statistical data for the Ingonish Island volcanic rocks

Sample Number	Rb (ppm)	Sr (ppm)	Rb/Sr (Weight)	$^{87}Rb/^{86}Sr$ (atomic)	$^{87}Sr/^{86}Sr \pm 2\sigma_M$* (atomic)
K09-6047	83.06	58.08	1.430	4.148	0.73101 ± 4
K09-6037	82.73	38.07	2.173	6.309	0.74312 ± 3
K09-6036	15.32	22.71	0.6746	1.954	0.71758 ± 5
K09-6034	84.56	53.00	1.595	4.628	0.73295 ± 3
K09-6026	95.11	75.36	1.262	3.658	0.72733 ± 3
K10-6994	94.26	170.8	0.5518	1.598	0.71528 ± 3

*2σM = 2 standard errors of the mean

For all 6 samples

Age ± 2σ *a priori* (scatter error) Ma = 416 ± 4 (12) Ma
($^{87}Sr/^{86}Sr$) initial ± 2σ *a priori* (scatter error) = 0.70588 ± 0.00015 (45)
SUMS = 36.6
MSWD = 9.15

For 5 samples (excluding K10-6994)

Age ± 2σ *a priori* (scatter error) Ma = 412 ± 5 (15) Ma
($^{87}Sr/^{86}Sr$) initial ± 2σ *a priori* (scatter error) = 0.70610 ± 23(74)
SUMS = 31.1
MSWD = 10.4

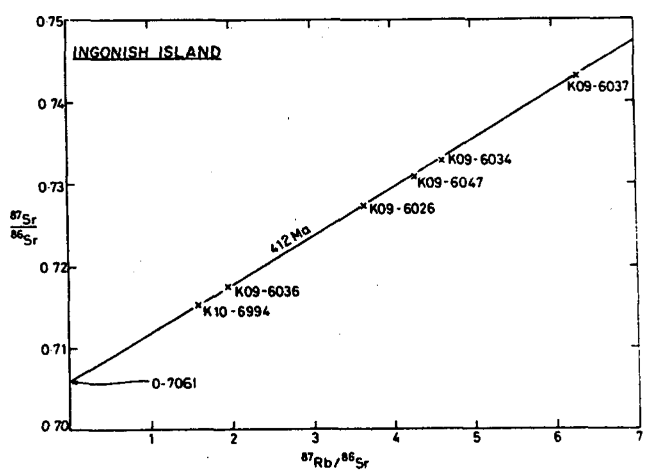

Figure 3. Rb-Sr whole rock isochron for the Ingonish Island volcanic rock.

the second phase of deformation. Two micrograntic plutons which intruded these metamorphic rocks at Cape North and Gulch Brook were inferred by Macdonald and Smith (1980) to be late-kinematic products of this metamorphism. However, the Gulch Brook microgranitic pluton, although texturally and compositionally similar to the pluton at Cape North, is distinctly more homogeneous and less strongly foliated. The area was then intruded by several post-tectonic, unfoliated granite plutons one of which yielded a Rb-Sr whole rock isochron age of 330 ± 23 Ma (Cormier, 1980).

The Gulch Brook microgranitic pluton is typically composed of quartz, microcline, perthitic orthoclase, oligoclase, biotite and minor muscovite and myrmekite. The foliation is defined by aligned biotite.

Isotopic data for seven samples from the Gulch Brook pluton are given in Table 3 and define a reasonably good whole rock isochron with an age of 413 ± 10 Ma (2σ scatter errors) (Fig. 4). The MSWD is 23.3 and the initial $^{87}Sr/^{86}Sr$ is 0.70446 ± 0.00043. This age again correlates with the 400-420 Ma age of the Acadian Orogeny (Keppie *et al.*, 1983). Thus, two

Table 3. Analytical and statistical data for the Gulch Brook micrograniitic pluton.

Sample Number	Rb (ppm)	Sr (ppm)	Rb/Sr (Weight)	$^{87}Rb/^{86}Sr$ (atomic)	$^{87}Sr/^{86}Sr \pm 2\sigma_M$* (atomic)
N01-1091	186.9	64.98	2.876	8.359	0.75365 ± 3
K16-0022	193.2	70.63	2.735	7.949	0.75199 ± 3
K16-1082	216.4	65.78	3.289	9.568	0.76166 ± 2
K16-1182	187.5	69.01	2.718	7.897	0.75124 ± 4
K16-1184	224.2	62.85	3.567	10.38	0.76544 ± 4
K10-1175	149.7	84.86	1.764	5.116	0.73317 ± 4
repeat	151.5	85.15	1.779	5.160	0.73326 ± 4
K16-1187	112.6	311.3	0.3616	1.046	0.71065 ± 4

*$2\sigma M$ = 2 standard errors of the mean
Age ± 2σ *a priori* (scatter error) Ma = 413 ± 2 (10) Ma
($^{87}Sr/^{86}Sr$) initial ± 2σ *a priori* (scatter error) = 0.70446 ± 9 (43)
SUMS = 117
MSWD = 23.3

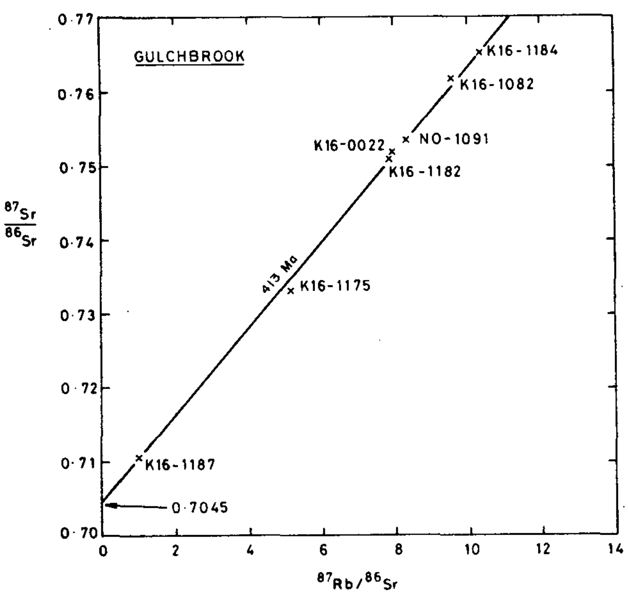

Figure 4. Rb-Sr whole rock isochron for the Gulch Brook pluton.

interpretations of the isotopic data are suggested:

(i) the microgranite is a late Precambrian-Cambrian pluton as postulated by Macdonald and Smith (1980) but the Rb-Sr system was completely reset by the effects of the Acadian Orogeny, which produced the foliation in the microgranite;

(ii) the age represents the crystallization age and intrusion took place during the Acadian Orogeny producing the internal foliation.

The former is considered unlikely because calculations assuming closed system redistribution of Rb and Sr at 413 Ma show that it requires an unrealistically low average $^{87}Rb/^{86}Sr$ of <1 for the pluton between (say) 600 Ma and 413 Ma, if its source region at 600 Ma had an $^{87}Sr/^{86}Sr$ of >0.702.

Two biotites and one muscovite fraction from samples of the Gulch Brook pluton yielded a mineral isochron age of 320 Ma (Cormier, 1980). However, the initial $^{87}Sr/^{86}Sr$ value thus obtained is unrealistically high at c. 0.830. Another approach is to calculate three separate mica ages assuming a reasonable initial $^{87}Sr/^{86}Sr$ ratio of 0.71 (Cormier, written communication, 1984). When this is done, the two biotites yield ages of 349 and 351 Ma whereas the muscovite gives an age of 363 Ma. These differences could be due to different blocking temperatures for biotite and muscovite. The larger difference between the whole rock isochron age and the mica ages could also be explained by slow cooling. However, the widespread angular unconformity beneath the Carboniferous rocks throughout Cape Breton Island indicates that uplift and erosion close to the present erosion level took place during the Devonian. Thus, the Carboniferous mica ages suggest that a later thermal event reset the Rb-Sr system at the scale of individual minerals. This thermal event may be associated with the intrusion of the 330 ± 23 Ma old pluton cropping out just to the north of the Gulch Brook pluton (Fig. 1c). However, this thermal event was not sufficiently intense to reset the whole rock Rb-Sr system. The $^{87}Sr/^{86}Sr$ initial ratio of 0.7045 ± 0.0004 indicates a lower crustal source for the magma although a mantle component could also be important.

CONCLUSIONS

The 407 ± 46 Ma Rb-Sr whole rock isochron age on deformed felsic volcanic rocks from the Precambrian Fourchu Group in Cape Breton Island is far too young, apparently recording the effects of resetting during the Acadian Orogeny. This shows that, although the Rb-Sr technique is unlikely to yield extrusive ages in deformed felsic volcanic rocks, it gives useful results when resetting of the Rb-Sr system is almost complete. Isotopic data for the weakly foliated Gulch Brook pluton suggests that it was intruded at 413 ± 10 Ma, even though individual micas in these rocks were reset during a Late Devonian-Early Carboniferous thermal event. In this case, the redistribution of Rb and Sr during the later event was limited to the scale of individual minerals, whereas hand specimens remained unaffected. The similar age (412 ± 15 Ma) of the Ingonish Island volcanic rocks suggests that they are extrusive equivalents of the Gulch Brook pluton. This is supported by their identical (within analytical errors) initial $^{87}Sr/^{86}Sr$ ratios.

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